An Integrated First-Year Curriculum in Science, Engineering, and Mathematics: Progress, Pitfalls, and Promise

Brian J. Winkel Jeffrey E. Froyd
Rose-Hulman Institute of Technology

History and Overview

During the spring of 1986 a small, informal group of faculty gathered regularly to discuss science, engineering, and mathematics at Rose-Hulman. From these discussions consensus emerged that we could do better, if we offered students a more coherent introduction which would relate topics offered in the first-year curriculum and use the concepts in one discipline to support concepts in another. A grant from the Lilly Endowment, Inc. supported five faculty during the summer of 1988 as they developed a syllabus for further consideration.

At the end of the summer of 1988 a sequence of three 12 credit courses: SE101, SE102, and SE103, called the Integrated First-Year Curriculum in Science, Engineering, and Mathematics (IFYCSEM) emerged with a syllabus and a structure. In IFYCSEM were integrated the concepts from ten required first-year courses.

Number	Course Title	Credits
MA111	Calculus I	5
MA112	Calculus II	5
MA113	Calculus III	5
PH125	Mechanics	
or		
EM120	Engineering Statics	4
PH135	Electricity and Magnetism	4
CM111	General Chemistry I	4
CM113	General Chemistry II	4
CS100	Introduction to Programming	2
EM103	Introduction to Design	2
EM104	Graphical Communication	2
TOTAL		37

After receiving faculty approval to offer the new curriculum for the first time in the fall of 1989 funding was sought to support the new curriculum. Three proposals were submitted to the National Science Foundation in the areas of curriculum development, computer laboratory equipment for physics instruction, and computer equipment for classroom use. All three were funded. Due to the late date of the announcement of the awards it was decided to postpone the attempt to offer the curriculum until the fall of 1990.

Our students have routine access to NeXT computer workstations (Originally, we purchased 70 workstations, outfitting two 30-machine classrooms and faculty offices. Now, we have almost 200 NeXT computers on campus and 5 30-machine classrooms.) with software applications such as *Mathematica* and FrameMaker. They can perform symbolic, numeric, and graphical manipulations routinely and prepare professional quality reports. A physics laboratory has 15 personal computers, each with an ultrasonic ranging system, various sensors, and data acquisition software. Data collected from the physics laboratory can be transferred to the NeXT network for manipulation and analysis.

IFYCSEM has been offered for two years. During the first year (1990-91) 60 students were selected for the program from volunteers and five faculty taught the course. The students were some of the best in the school. These five faculty had worked during the summers of 1989 and 1990 to build the curriculum, integrate the material where possible, and prepare materials and software applications for the course. Thirty-eight students successfully completed the first year's sequence.

In the second year (1991-92) 120 volunteers enrolled (first come, first serve) in the course which was taught by 7 faculty. The demographics (SAT scores, high school rank, etc.) of the students who elected to enroll in the IFYCSEM were almost identical to the rest of the first-year class. Thus, we believe we had a good cross-section of the student body population. 68 students completed the course. We usually have about a 1/6 attrition rate due to calculus difficulties in the first year. In addition, students perceived that IFYCSEM was harder and more demanding than the traditional curriculum. As a result, 25 students who had received C's or better withdrew after the fall quarter. These factors explain the large attrition rate.

In the third year (1992-93) we have 90 volunteers students (again with, we believe, no significant difference between the volunteers and the rest of the first-year class) being taught by 8 faculty. We believe this will be a more reasonable student/faculty ratio. In addition, we have instituted a number of measures to improve student retention. These include: 1) early introduction to the NeXT workstations during new student orientation in the fall; 2) weekly meetings with advisors; 3) student assistants in the classrooms and laboratories during the early weeks of the curriculum for immediate help; 4) closer ties with the Learning Center;

5) journal writing each night for reflection purposes; 6) a Mentor program in which successful alumni of the IFYCSEM will meet informally with 3-4 new students on a regular basis during the start of the course; and 7) an IFYCSEM student council for meaningful dialogue between students and faculty in the course.

Rational for the IFYCSEM

The IFYCSEM was initiated to address two main weaknesses in the traditional curriculum:

1) overemphasis on rote manipulation, and

2) failure to make connections among the topics that are studied in different disciplines.

The remedy for the first weakness is to stress problem solving at the expense of rote manipulations: more situations are presented (written or oral) in students formulate strategies to reach a solution and then evaluate the reasonableness of their solutions. The remedy for the second weakness is to stress thematic concepts (e.g. rate, accumulation, and conservation) that cross disciplines as opposed to individual topics. In addition, between 4 and 6 design project experiences are woven into the curriculum. In all cases the appropriate use of technology as a regular problem solving tool is stressed.

Learning and Teaching in the IFYCSEM Human Interface

As teachers, we would like to share with our experiences in teaching IFYCSEM for two years and how we have been changed through these experiences. We hope these insights will be valuable in your innovations. We will group these insights into several categories according to the relationships involved.

a. faculty-faculty interfaces -- technical
b. faculty-faculty interfaces -- pedagogical
c. faculty-faculty interfaces -- personal
d. faculty-student interfaces
e. student-student interfaces

a. Faculty-Faculty Interfaces-- Technical

For the faculty there have a number of technical advantages to teaching in the IFYCSEM:

(1) learn material from other disciplines;
(2) learn value of particular concepts in other disciplines;
(3) learn importance of the flow of topics in other disciplines;
(4) learn and experience laboratory activities in other disciplines;
(5) learn relationships between topics;
(6) learn the difference in notation, e.g., The term torque is used in physics and moment of force is used in statics for the same concept, but torque is never mentioned in statics text (Beer and Johnston) and moment of force is never mentioned in physics text (Halliday and Resnick).
(7) develop a willingness to change the order of presentation to accommodate needs of other disciplines; This willingness leads to entirely new approaches, e.g., moment of inertia was used to motivate multiple integrals (in a traditional calculus text moment of inertia is an application of multiple integrals). Also, kinetics (velocity, acceleration) was used to motive derivatives.
(8) use textbooks outside your discipline for new sources of problems and examples; Several students enjoyed problem-solving sessions in which problems from several different disciplines were offered. "This is what I thought IFYCSEM was about," stated one student in this year's IFYCSEM council.
(9) understand what first-year students are learning and their capabilities;

b. Faculty-Faculty Interface - Pedagogical

(1) visit other teachers' classrooms informally and regularly to observe other teaching styles and learn about their pedagogical approaches;
(2) swap methods, ideas;
(3) talk on a regular, team basis to colleagues from other departments;
(4) team design and grading of exams - it's an experience;
(5) team grading of design reports;
(6) small groups and problem-solving;
(7) collegial support for experimentation; It is easier to try new ideas, e.g., Whimbey pairs, with the support of other colleagues.
(8) coaching mode is more productive and peer group of faculty give more support
"I coach at Purdue." (Ed Dubinsky).

c. Faculty-Faculty Interface - Personal

(1) develop a team concept and spirit;
(2) develop group skills in a new setting;
(3) develop new friendships;
(4) discuss issues beyond departmental boundaries;
(5) get away from departmental politics, fresh start;
(6) develop a sense of community with colleagues across the Institute

d. Student-Faculty Interface

(1) students interact in small groups in class instead of watching a lecture;
(2) student council meetings to discuss course issues;
(3) perceived differences in IFYCSEM encourages faculty dialogue with students about their experiences and reactions;
(4) reactions to the planned mentoring program - 25 out of 40 students asked to mentor were enthusiastic and willing to serve;
(5) dealing with students who are asking faculty questions outside their discipline;
(6) faculty might do poorly on IFYCSEM exams;
(7) students get to see and interact with engineering faculty in first year;

(8) students get to see faculty interact to solve problems, to discuss pedagogical approaches;
(9) faculty watch students progress from solving simple one step problems to solving more complex problems.

For example consider the following two problems in calculus.

Problem 1 - optimization

The speed of sound in various media can be used to confirm geological models of the near surface of the earth. For example, the speed of sound in silver is 2640 m/sec, in clay/rock is 3480 m/sec, and in iron is 5130 m/sec.

Consider the following diagram which is the result of geological probing in western Kansas. Distances are in 100 m. The origin, O, is at a depth of 600 m. The surface is 600 m above the origin O in the plot below. The conjecture is that silver is in the region bounded above by the function y = f(x) and below by the x-axis; iron lies in the region bounded below by the function y = f(x) and above by the function y = g(x); and clay/rock lies above the function y = g(x) and below the surface.

A sound generator is placed in a hole, 600 m deep, at the origin O = (0,0). Sounds are generated and recorded at the points A, B, and C near the surface, i.e., A = (4,5.5), B = (6,5.5), and C = (8,5.5).

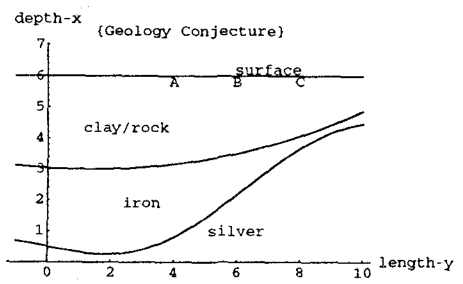


Figure 1. Drawing for optimization problem.

With sensitive equipment it is determined that the time it takes the sound to go from point O to the respective points A, B, and C is
0.0017 sec for the sound to reach point A;
0.0020 sec for the sound to reach point B; and
0.0022 sec for the sound to reach point C.
Prepare a document which either supports or refutes the geological model of this underground region. Defend your decision with solid mathematical evidence. Make suggestions as to how the model could be better assessed.

Problem 2 - multivariate calculus

For the function $f(x, y) = (x^3 - 3x + 4)/(x^4 + 5y^4 + 20)$ suppose your eye is precisely on the surface of z = f(x, y) at the point (2.8, .5, f[2.8,.5]) - dark dot seen on the surface in figure below. You look to the west, i.e. in the direction (roughly) (-1, 0, 0). You see a mountain before you.
(a) Determine the point on the mountain which you can see which is nearest to you.
(b) Describe as best you can the points on the mountain which you can see from the point (2.8, .5, f[2.8,.5]).

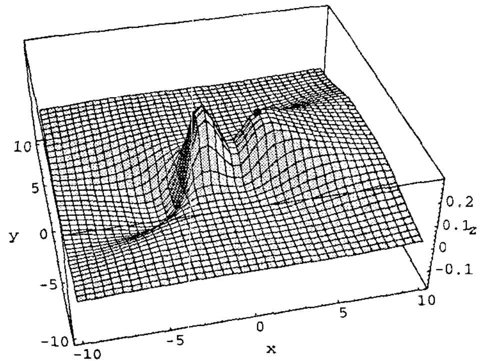


Figure 2. Plot of the point (2.8, 0.5, f(2.8,0.5)) on the surface $f(x,y) = (x^3 - 3x + 4)/(x^4 + 5y^4 + 20)$.

e. Student-Student Interface

(1) small group work in class and on projects;
(2) design teams for major design projects;
(3) general cooperation, helping each other;
(4) interaction is assisted by computer labs which provide gathering points;
(5) students are hired in the fall quarter during class and open evening lab hours to help teacher as students learn to use the computer;

Design projects

In the first year of the curriculum (1990-91) we had six design projects. This proved to be a burden on the students as each of these was "on top" of the running curriculum. In the second year we opted for four design projects with more time for each project and a corresponding reduction in other assignments:

1. helicopter design from 81/2 x 11 sheet of paper, a paper clip, and 12 inches of Scotch tape;
2. ball performance: students defined and measured the performance of a ball;
3. two parts - baking soda and vinegar
   part 1 - measure energy released in reaction
   part 2 - design a (land, sea, or air) vehicle propelled by the reaction;
4. two choices
   choice 1 - design an improved air cart for air tables in the physics laboratory, raise the center of mass for improved collisions
   choice 2 - design a NeXT application which you think would help students next year learn a concept which gave you difficulty.

We learned from first to second to third year.

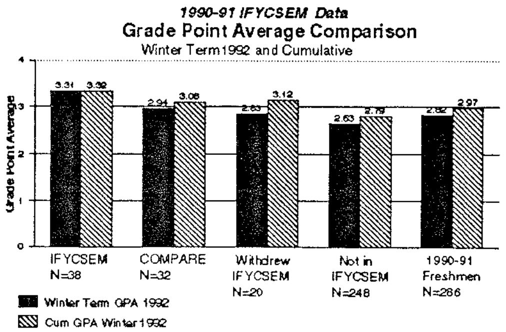
As we have been sensitized to the pace at which students can learn NeXT interface and capabilities and *Mathematica* language and use, we slowed the pace and instituted an introduction to the NeXT in first-year student orientation. We created a number of applications with Interface Builder, but it has taken time for us to integrate into the course. We have increased their use of applications (e.g. Physics World, Data Explorer) both in the curriculum and throughout the Institute. In the first year, we introduced Objective C and Interface Builder programming in the first quarter. In the second and third year, we first introduced programming in *Mathematica*, then programming in C, and finally we did programming in Objective C with InterfaceBuilder. In addition, there was an optional Objective C programming design project.

Mathematica, C (Real), Objective C and InterfaceBuilder Programming

In the second and third years we used *Mathematica* to introduce fundamental programming concepts: loops, iteration, functions, etc. For their first *Mathematica* programming assignment students modeled a projectile motion with air resistance, i.e., they coded Euler's method for solving a first order differential equation and used the graphics capability of *Mathematica* to animate the flight. After several other *Mathematica* programming assignments we then proceeded to C programming. Many students (especially computer science students) were relieved when they started studying C which they considered a "real" programming language as opposed to *Mathematica.* Then, we introduced the Objective C programming language and the NeXT development environment including InterfaceBuilder. Students with their background in C and their knowledge of Objective C and InterfaceBuilder were soon creating applications with windows, buttons, sliders, and menus just like the NeXT applications they used throughout the year. (Note: From the IFYCSEM students we have hired some outstanding software developers to work with us in the summers on very significant projects. Many of the InterfaceBuilder applications developed by our student developers and used in our IFYCSEM efforts are available on a CD-ROM offered by NeXT Computer, Inc. All are available by anonymous ftp from Rose-Hulman. Contact the second author for details.)

Evaluation

We have had an on-going effort to evaluate IFYCSEM. Dr. Gloria Rogers, Assistant to the Dean of the Faculty, and Dr. Patrick Brophy, Professor of Psychology, have directed these efforts. For each class in the IFYCSEM control groups have been selected using cluster analysis. Tracking of the performance of both groups is proceeding.



Results of pre- and post-testing on (1) a mechanics misconception test and (2) the Watson-Glazer Critical Thinking show no significant difference between the beginning and end of the first-year for either the IFYCSEM group or the control group. However, the IFYCSEM students in our first year offering did do better in their winter term grades during the following sophomore year as evidenced by the data shown.

In addition, Dr. Rogers conducted a blind survey of all of the faculty teaching second-year courses in which either IFYCSEM or control group students had enrolled. She asked the faculty to rate students on six attributes deemed appropriate for sound science and engineering education. Faculty were polled and each was asked to assess individual students (using randomly chosen students to fill out to a list of 10 where necessary). The following scale was used:

Lowest... Highest
1----2----3----4----5----6----7----8----9----10

Below are the questions posed:

1. can develop an idea to its appropriate conclusion.
2. relates new experiences and concepts to prior knowledge and experience.
3. communicates ideas effectively and easily.
4. demonstrates an attitude which is appropriate for learning.
5. ability to integrate the use of computer for problem solving in this class is:
6. describe the type of scientist or engineer you project that this student will become.

The data showed that for qualities 1, 2, 3, 5, and 6 there was a significant difference (at the $\alpha = .05$ level) in faculty observations with the IFYCSEM students scoring higher in faculty rankings.

In addition to the formal evaluation procedures, we have a wealth of anecdotal data about student reactions to IFYCSEM, both pro and con (see appendix). In summary, we believe that students who succeed have developed the qualities we seek in an engineer: perseverance, ability to synthesize topics from different disciplines, ability to use a computer routinely as a tool, willingness to tackle tough, complex problems, willingness to see and accept help from peers and faculty, and enthusiasm for teamwork, interdisciplinary approaches in science and engineering.

Now, our opportunity is to convince students who begin the curriculum that the rough spots (when compared to the traditional curriculum) are but growing times in which their capabilities are expanding. Further, if they stay with it, their efforts will pay off. Alumni from the curriculum now can show the way as they progress into their sophomore and junior years and this helps our task a great deal.

Sam Hite, the former head of our Chemical Engineering Department, when presented with the goals of the curriculum early in its development said, "Well, that is exactly what we hope to accomplish with our graduating majors. How do you plan to accomplish that in one year?" We told Sam and we tell all who will listen, "We hope to start the students on the path toward becoming productive problem solvers who are willing to reach for new approaches, new ideas, new disciplines, and new technologies to achieve their goals. We believe an integrated first-year curriculum in science, engineering, and mathematics is an excellent way to achieve the personal and professional goals of our students."

Invitation to Engage in Dialogue

Further information is available from the second author. Information includes details on how to anonymous ftp course materials: NeXT applications, course *Mathematica* notebooks, information on evaluation of the project, site visits to Rose-Hulman, and visits by Rose-Hulman personnel to your campus to meet with your faculty who might wish to consider a course like IFYCSEM or exchange ideas.

Acknowledgments

This work is based upon work supported by the National Science Foundation under Grant Numbers USE-8953553, USE-8951290, and USE-8950669. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. Additional major grants from the Lilly Endowment, Inc., the GE Foundation, and the Westinghouse Foundation have supported this curriculum.

Appendix - Student Responses: Fall Quarter 1991-92

We polled the students from the second year of the curriculum at the end of their first term in the curriculum. Among the questions we had a most meaningful question. We summarize the responses and offer typical answers.

> Do you wish to remain in this curriculum?
> Why? If not, why not?

72 Yes; 26 No; 7 Maybe

Yes responses (sampled):

Because the material is stuff I can actually apply in the real world.

The course is very tough, but you learn many problem-solving abilities.

I enjoy challenges and new ideas.

I am in the groove of things and can better my grade next quarter.

The last few weeks, we've been doing problems that required us to bring together many ideas that we've been working on. This seemed to be the moment that justified all the weeks of stress and strain.

I intend to remain in this curriculum because, even though it is difficult now, I feel that ultimately I will greatly benefit from this experience.

Because it will help me in the long run.

I am learning skills here that are left out in normal curriculum.

I like it when everything is grouped together.

I think one quarter is not a long enough time for me to completely abandon the curriculum.

It would be too easy just to drop out and learn the same way I learned things in high school. This approach isn't the easiest way for me to learn under, but I feel that the real world won't be any easier.

I am understanding ideas which I am sure would have slipped by me in another class.

I am hoping that I will learn a lot more and have a better problem solving base in the future.

I like the projects, the teachers, and I hope it will become less stressful and more integrated.

I don't want to quit just because I hate quitting anything and I think that I will be able to gain facts and skills that the regular curriculum won't have.

I think I will be able to solve complex problems far better than non-IC people. My roommate who is not in IC spends most of his time doing routine work which is too simple.

I feel I am learning more in IFYCSEM than I would in the regular curriculum and I honestly believe my grades would be the same.

I came to Rose to earn a degree which necessitates learning a lot of stuff and you learn more in IC.

I like concepts tied together and the responses our comments get.

No responses (sampled)

Students taking the curriculum need to have prior knowledge and no desire to participate in many extra-curriculum activities.

It's too fast and too hard and it takes too much of my time. Education is important, but my life (and how I balance it) is more important to me

If I remain in this curriculum, I can say good-bye to my future at Rose-Hulman.

I want some free time, and, I want to get better grades. But I like the professors.

I feel that I will learn more and be more comfortable outside of the curriculum.

I don't feel that it is my advantage to stay. Despite what the statistics say, I know I'd do a lot better in the traditional curriculum.

I have other concerns outside IC. I am very athletic and would like to pursue that and I would also like to enjoy other things Rose has to offer..

Too much work, the GPA (as you say) will remain close to the same for most, but the work load will go down. There is more to college than work.

Maybe responses (sampled)

If I think I can learn how to solve the problems quicker than I am now I would want to stay. However, if I end up with as poor a grade as I think I am getting I am going to drop this curriculum and attempt the straight curriculum.

I must determine in my own mind if I am learning what I feel I should or if I am just regurgitating what I did on my homework.

Brian J. Winkel

Dr. Brian J. Winkel is professor of mathematics at Rose-Hulman Institute of Technology. He has been at Rose-Hulman since 1981. His professional interests include editing three journals, Cryptologia, Collegiate Microcomputer, and PRIMUS; planning and teaching new courses, e.g. cryptology, mathematical modeling, and the integrated first-year curriculum in science, engineering, and mathematics; and using technology, specifically Mathematica, in enhancing teaching.

Jeffrey E. Froyd

Dr. Jeffrey E. Froyd is a professor of electrical and computer engineering at Rose-Hulman Institute of Technology. He has been at Rose-Hulman since 1981. His research interests include control system design, neural networks, fuzzy logic, and semiconductor device modeling. In teaching, he has focused on efforts to integrate concepts in the four-year engineering curricula and to make computers a part of a more productive educational environment.